

SOCIO-ECONOMIC IMPACTS OF FUTURE MOBILITY DISRUPTION SCENARIOS

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A transition towards Autonomous, Connected and Electric (ACE) Vehicles on the road is likely to have significant socio-economic implications beyond the impacts foreseen in the passenger and freight transport sectors. This paper explores how the deployment of these technologies may impact the European Union's economy, employment and emissions. Impacts identified as relevant in the literature (on vehicle manufacturing, materials, fuel consumption, emissions, maintenance and repair services, etc.) are analysed through scenario analysis using a multi-sectoral economy-energy-environment computable general equilibrium model: the JRC-GEM-E3. As a global CGE model, the JRC-GEM-E3 is extended to identify key sectors and relationships of interest between road transport activity, fuel consumption, emissions and the rest of the economy. Three scenarios varying in terms of technology deployment and vehicle usage are modelled against a baseline, to identify and disentangle the potential impacts of ACE trends on the EU economy and the environment.

Keywords: Electrification; Road transport; Automated Connected Vehicles; Computable General Equilibrium;

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1. Introduction

In the context of digitalisation and decarbonisation, the transport sector may undergo radical transformations in the decades to come. In particular, four key trends hold a significant disruptive potential for road transport: Automation, Connectivity and Electrification (ACE).

Road transport electrification has already begun and is accelerating in recent years, with 1.1 million new electric cars sold globally in 2017 (including plug-in hybrids, battery electric and hydrogen fuel cell vehicles), a 54% year-on-year increase (IEA, 2018). In contrast, vehicle automation³ and connectivity⁴, two highly complementary technology developments, are relatively less mature. While vehicles with assisted driving functionalities (e.g. adaptive cruise control or parking assistance) are already available in the market (ERTRAC, 2019), full automated driving systems (without human intervention) are still under development to ensure safe vehicle operation (Claybrook and Kildare, 2018).

The increasing uptake of ACE in road transport are expected to lead to significant changes in terms of vehicle ownership and activity, vehicle manufacturing, traffic flows and volumes, accidents and commuting times (Arbib and Seba, 2017, Wadud et al. 2016, Chase et al. 2018). The macroeconomic and societal implications of a potential mobility revolution will be more widespread than the transport sector, notably in terms of employment, economic growth, energy use and emissions of greenhouse gases and other pollutants.

This paper explores how the deployment of ACES in road transport may impact the European Union's economy, employment and emissions. A number of impacts are in focus for this analysis. First, as new automation, connectivity and electric technologies for cars and trucks develop, the manufacturing of vehicles will change, with ramifications throughout the entire supply chain. Second, as these new vehicles penetrate the passenger and freight transport markets and the vehicle stock is renewed, further socio-economic shifts will result from their use on the road. First, the fuel mix and fuel efficiency will gradually evolve, together with emission intensity, with economic implications across energy extraction, production and distribution sectors. Second, they will further affect demand for other goods and services, such as repair and maintenance, spare components, freight and passenger transport services.

This paper explores the issues identified above through scenario analysis using a multi-sectoral economy-energy-environment computable general equilibrium model: the JRC-GEM-E3. As a global CGE model, the JRC-GEM-E3 is particularly well-suited to the analysis of the ACE transformations in road transport for Europe, as the risks and opportunities for the EU economy will

³ Automated driving systems Different levels of vehicle automation exist

⁴ Use of technologies to enable vehicles to communicate with each other and roadside infrastructure

greatly depend on developing and maintain innovation leadership and competitiveness on key global markets.

Section 2 reviews the literature on the macroeconomic and employment impacts of. Section 3 provides an overview of the methods used for analysis, from a description of the model and its key transport features to the extensions required for the present analysis. The key scenario assumptions are summarised in Section 4, while Section 5 discusses the results of the modelling. Section 6 provides conclusions and [].

2. Literature Review

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3. Methods

The analysis of economic and environmental impacts of ACES trends in road transport is based on the modelling of potential future mobility scenarios, using a global energy-environment augmented Computable General Equilibrium model: the JRC-GEM-E3. First, the main features of the model are presented, with a special focus on the representation of road transport. Second, the model extensions to represent Automation, Connectivity, Electrification and Shared mobility are presented, including underlying data sources and assumptions.

3.1. Model

The JRC-GEM-E3⁵ (General Equilibrium Model for Economy-Energy-Environment) is a recursive dynamic CGE model. Based on the GTAP database v9.2 (Aguiar et al., 2016), it is a global model, covering the European Union, alongside 12 other major countries or world regions. With a detailed sectoral disaggregation of energy activities (from extraction to production to distribution sectors) as well as endogenous mechanisms to meet carbon emission constraints, the JRC-GEM-E3 has been extensively used for the economic analysis of climate and energy policy impacts (see Keramidas et al, 2018 or Vandyck et al., 2018 for recent examples).

Firms are cost-minimizing under CES production functions and are divided into 31 sectors of activity, with an emphasis on energy intensive industries (e.g. Iron and steel, chemicals) and energy production and supply (including 8 electricity generation sectors, 1 electricity distribution and transmission sectors, 3 fossil fuel production sectors)⁶. Sectors are interlinked by providing goods and services as intermediate production inputs to other sectors, used in combination with factors of productions (labour, skilled or unskilled, and capital).

⁵ For a detailed description of the model, see Capros et al., 2013.

⁶ Different CES nested production structures are defined for energy sectors (extraction, electricity generation or electricity distribution) compared to the rest of the economy.

Households are the owner of the factors of production and receive income, used to maximize utility through consumption. Household consumption is characterised by Stone-Geary preferences with minimum subsistence levels, split between 14 different consumption good categories. A distinction is made between durable goods (heating and cooking equipment, private vehicles) and non-durable goods. The use of durable good is

Government is considered exogenous, while bilateral trade-flows are allowed between countries and regions. In 5-year steps, from 2015 out to 2050, equilibrium is achieved at the global level on goods and services markets, and for factors of production through adjustments in prices.

3.2. Road transport in the JRC-GEM-E3

Transport activity is considered both an input to production for firms, and a consumption category for households. Transport services (both passenger and freight) are provided through three distinct economic sectors in the model: Air Transport, Water Transport and Land Transport, corresponding 1-1 to the three transport services sectors in GTAP. Road transport is not singled out as a separate economic activity, but is captured within the broader land transport sector⁷. Importantly, it does not fully cover transport activity which takes place by road in the economy, since it only accounts for goods sold over a market, and does not capture "own transport" activity, carried out either as an *ancillary activity* in other economic sectors or by households directly through the use of their private vehicles.

3.2.1. Transport as an input to production

Each economic sector relies on road transport as input to the production process: (a) in the sector's intermediate input expenditures on land transport and (b) in the sector's own capital stock (its own vehicles).

The use of land transport as intermediate inputs in each sector is represented in Figure 1, which shows that transport sectors are themselves the main source of demand for land transport services as intermediate inputs (e.g. land transport services represent over 43.1% of total intermediate inputs used by land transport services in the EU). Therefore, diffusion of technological innovation in road transport will more directly affect transport-services sectors, while indicating potential multiplier effects.

⁷ For the EU, land transport includes the following NACE Rev.2 activities (Rueda-Cantuche et al, 2016): H49: Land transport and transport via pipelines (incl. road/rail and passenger/freight); H52: Warehousing and support activities for transportation; N79: Travel agency, tour operator reservation service and related activities.

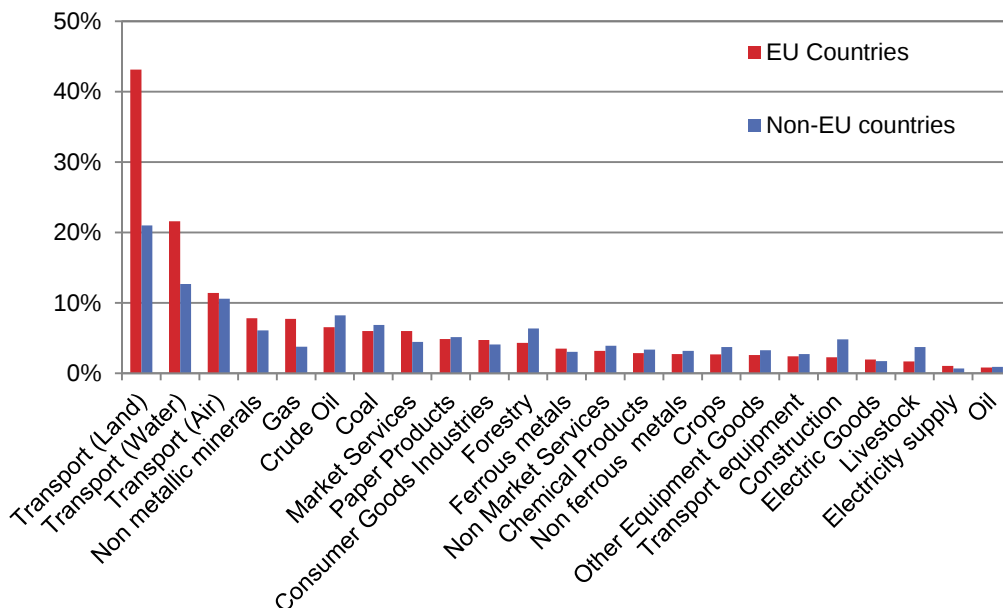


Figure 1: Average share of land transport services in intermediate inputs demand
based on GTAP v.9 aggregated for JRC-GEM-E3 sectors (omits electricity generation sectors)

Each sector also relies on its own capital stock as a production factor, which partly captures its own vehicles. In the JRC-GEM-E3, firms invest in new capital in each modelling period in anticipation of expected demand in the next period. While investment demand in each period is sector-specific, capital mobility is assumed across sectors in subsequent periods.

This investment demand is supplied by sectors in the economy themselves, and the supply-use allocation of capital goods is made through the use of an investment matrix (decomposing capital stock into goods and services). In general, in the absence of data to complement investment supply and investment demand totals from GTAP, one investment matrix is derived for each country based on the share of each sector in total investment supply.

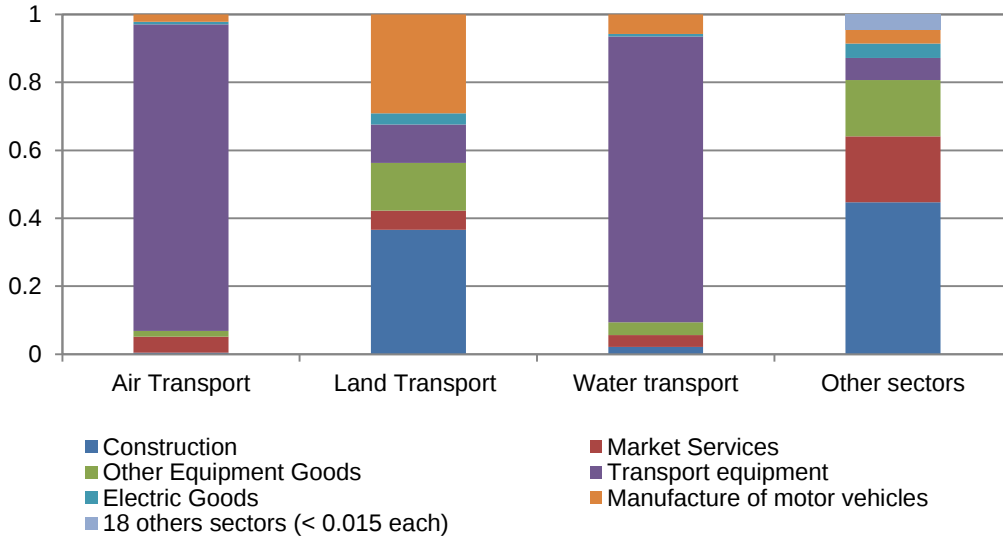


Figure 2: Global average investment matrices, based on Eurostat nama_10_nfa_fl, 2016 for transport sectors.

Using available EU data on gross fixed capital formation by industry and asset (Eurostat, 2016), transport sector specific investment matrices are derived in the JRC-GEM-E3 sectoral aggregation, to reflect the higher share of transport equipment in investment in new capital stock compared to other sectors. The global averages of the investment matrices used in the current modelling exercise are presented in Figure 2. Using these investment matrices, the deployment of new technologies in road transport in the modelling exercise should emerge more rapidly in transport services sectors than in the rest of the economy.

3.2.2. Household transport

In the model, household consumption is categorized into 14 purpose groups, of which 3 are transport-related: Purchase of vehicles, Operation of personal transport equipment and Transport services. The first two categories correspond to private transport while transport services refer to expenditures on externally provided services (e.g. public transport by bus/train, hired taxi/cars, planes, ships, etc.).

Household expenditures by consumption categories (denoted $HCFV_{fn,er}$ where subscripts fn and er correspond respectively to consumption category and country or region, respectively) are converted into consumption of goods and service (the 31 sectors of activity) through exogenously defined consumption matrices, where $thcfv_{pr,fn,er}$ is the share of sector pr supplied to satisfy consumption category fn . Total household final expenditure on sector pr , $HCV_{pr,er}$ is defined as:

$$HCV_{pr,er} = \sum_{fn} \left(\frac{thcf v_{pr,fn,er}}{e^{tgqtch_{pr,fn,er}}} \cdot HCFV_{fn,er} \right) \quad (1)$$

Where *tgqtch* represents a productivity parameter in consumption of a sectoral input. The matrices of consumption coefficients are presented in Table 1 for the three household transport consumption categories defined above.

Table 1. Consumption matrices for transport categories. Average input of sectors, %.

Purchase of vehicles	EU	ROW
Manufacture of motor vehicles	63.98%	61.17%
Market Services	29.78%	28.66%
Transport equipment	6.24%	10.17%
Others (<0.0001 each)	0.00%	0.00%
Operation of personal transport equipment	EU	ROW
Market Services	45.67%	37.39%
Oil	38.25%	43.38%
Transport (Land)	5.64%	6.58%
Non Market Services	2.74%	5.36%
Chemical Products	3.24%	3.46%
Manufacture of motor vehicles	2.79%	3.22%
Transport equipment	0.89%	0.32%
Other Equipment Goods	0.48%	0.19%
Electric Goods	0.24%	0.00%
Non-ferrous metals	0.06%	0.10%
Others (<0.01 each)	0.01%	0.00%
Transport services –	EU	ROW
Transport (Land)	59.27%	64.37%
Transport (Air)	31.93%	26.60%
Transport (Water)	8.61%	9.03%
Transport equipment	0.19%	0.00%
Others (<0.001 each)	0.00%	0.00%

3.3. Model extensions for Automation, Connectivity and Electrification

In order to represent the shifts in road transport technologies, as well as their potential impacts on economic activity, a number of new model features are developed.

3.3.1. New sectors for vehicle manufacturing

The default version of the model represents 31 sectors of activity, one of which being a transport equipment manufacturing. For analyzing the deployment of new vehicle technologies in the model, two new sectors are introduced. First, the manufacturing of vehicle sector is separated out of the total transport equipment activity, based on the existing GTAP sectoral disaggregation: manufacture of motor vehicles and other transport equipment⁸.

Additionally, a new sector is created to represent the manufacturing of electric vehicles, a virtually non-existent activity in the base year data (2011). The production structure of this new activity is computed through a modification of the structure of the conventional vehicle manufacturing in the EU, to reflect the different engineering composition of vehicles. With a fundamentally different and less complex powertrain technology than the internal combustion engine, electric vehicles are also composed of less moving and wearing parts (UBS, 2017), while the battery currently represents a significant share of the vehicle costs (BNEF, 2017a). Moving from conventional to electric vehicles, and assuming a similar vehicle body, a shift in composition is assumed (in value) from the removal of the combustion engine towards the purchase of a battery. Weighted by the share of each vehicle segment, the difference in total production costs is assumed to correspond to the difference average pre-tax price (BNEF, 2017b for small/medium/large vehicles, and based on Renault suggested pre-tax retail price for light-duty vehicles). The required capital and labour inputs for one unit of production is assumed to be the same between the two vehicles types⁹.

Table 2 presents the resulting production input structure in shares for both sectors. While manufacturing of conventional vehicles relies most heavily on own inputs (capturing chassis and engine components and parts), manufacturing costs for electric vehicle are approximately 50% attributable to the battery costs.

Table 2. Input structure of manufacturing of motor vehicles. Input share.

⁸ The JRC-GEM-E3 sector of manufacture of motor vehicles (sector 32) corresponds 1-to-1 to the GTAP sector 38 mvh - Motor vehicles and parts (NACE C29). Similarly, the JRC-GEM-E3 sector "Other transport equipment" corresponds 1-to-1 to GTAP sector 39 otn "Transport equipment n.e.c" (NACE C30).

⁹ Variations in labour inputs from the reduced assembly complexity will be explored in the sensitivity analysis.

	Manufacture of conventional vehicles	Manufacture of electric vehicles
Manufacture of conventional vehicles	0.283	0.000
Manufacture of electric vehicles	0.000	0.132
Market Services	0.147	0.092
Other Equipment Goods*	0.141	0.508
Non-ferrous metals	0.085	0.053
Chemical Products	0.065	0.040
Ferrous metals	0.034	0.021
Transport (Land)	0.020	0.013
Consumer Goods Industries	0.010	0.006
Electric Goods	0.008	0.005
Non-metallic minerals	0.015	0.009
Others (< less than 0.01 each)	0.026	0.016
Value Added	0.167	0.104

*Sector 14 – Other equipment goods includes the production of batteries (corresponding to NACE Rev.2 C27).

3.3.2. New vehicle deployment

The two vehicle types are considered substitutes, and households and firms are assumed to move gradually from conventional towards electric vehicles over the projection period. This shift is imposed through rendering the above consumption and investment matrices time-dependent.

For households, the share of manufacturing of conventional vehicle in the purchase of new vehicles is progressively shifted from conventional to electric vehicles using exogenous penetration rate projections for private cars based on scenarios derived through energy system models (see section 4 on scenarios). A similar approach is applied to the investment matrix for the deployment of EVs on the production side of the economy, using a different penetration rate corresponding to vehicles used for freight and public transport. This approach also allows for differentiating the penetration rate of new vehicle technologies across sectors (e.g. if land transport services are early-adopters).

For the deployment of Connected and Autonomous vehicles, a different approach is followed, requiring the purchase of a new vehicle (either conventional or electric) to be associated with an additional expenditure, allocated to the electronic goods and market services sectors, representing the additional costs of the software and hardware package (which enable automation and connectivity of vehicles to other vehicles and road infrastructure).

3.3.3. Vehicle operation (fuel mix, fuel efficiency, costs, labour inputs)

The deployment of electric vehicles will be associated with changes in operation of vehicles (and operating costs) both for households and production sectors, most notably in terms of fuel consumption. For households' private transport, the consumption matrix is also adjusted reflect the evolution of the fuel mix towards electrification, alongside general fuel efficiency improvement to capture the change in total fuel consumption per vehicle kilometer over time (using consistent inputs from the same energy system scenarios as for deployment). On the production side, a similar approach is followed using the share of fuels in total intermediate inputs for sectors with an evolving vehicle fleet.

In addition to the fuel mix changes, electric vehicles are expected to be associated with lower maintenance costs than internal combustion engine vehicles (Palmer et al., 2018, Letmathe and Soares, 2017). This can be reflected in the model through an increased productivity of maintenance (services) sector inputs in the operation of vehicles for households, and as intermediate inputs for production sectors. Despite a potential for improving road safety and reducing crashes (Thierer and Hagemann, 2015), the effect of automation on maintenance and repair costs is currently not fully understood (e.g. reduced wear and tear from more efficient use, higher labour and equipment costs, Wadud, 2017), and therefore not included in this analysis.

Finally, one of the most significant impacts of the introduction of autonomous driving system is likely to be on the labour market. While the impact on passengers is not straightforward (e.g. increased labour productivity from more efficient use of travel times, Leech et al., 2015), for the providers of transport services, this will translate into changes in labour input requirements. On the one hand, as driving tasks are more and more performed by the vehicle itself, the number of driver jobs might decrease (see for example ITF, 2017 for road freight transport projections), while on the other hand, the need for ICT-related skills in transportation will increase (Skillful Project, 2017, CEDEFOP, 2014). Overall, CAVs might change the skill composition in a transport sectors, requiring flexibility in labour supply (e.g. sectoral mobility). In modelling terms, this is captured through productivity shifts in high-skill and low skill labour.

3.3.4. Other modelling elements

While the relatively higher cost of EVs compared to their equivalent internal combustion engine vehicle options remains a key barrier to adoption, battery costs are widely expected to fall sharply with accelerating adoption of the technology. For example, the costs of li-ion battery packs (the most prominent technology in EVs sales worldwide to date) are expected to fall rapidly, with learning rates of approximately 16% (unit cost reductions for each doubling of production capacity; Tsiropoulos et al. 2018 provides a recent review of literature estimating learning rates for EVs). This learning rate is applied in the modelling

as a productivity improvement in the provision of batteries as intermediate inputs for the manufacturing of electric vehicles, linked to the deployment rate of EVs. Similarly, the costs of the CAV components is expected to reduce over time through learning effects.

The deployment and adoption of both EVs and CAVs will be dependent on investments in the necessary enabling infrastructure. The EU has put in place requirements on Member States on the deployment of alternative fuels infrastructure to ensure that an appropriate number of recharging points for EVs are made available to the public¹⁰, and more recently has underlined the importance of connectivity and digital infrastructure development in deploying CAVs (European Commission, 2018). Expenditures in both electric charging and ITS infrastructure are estimated and applied in the scenario through additional expenditures supplied by other sectors (in majority construction).

In addition to technology and infrastructure costs, the results of the analysis will also be highly dependent on assumptions made in other parts of the model, such as trade and electricity generation. Electrification of road transport has the potential to reduce greenhouse gas (GHG) emissions by reducing vehicle combustion of fossil fuels. An overall reduction in GHG emissions will be highly dependent on the evolution of the electricity generation mix away from fossil fuels. In the model, the evolution of the generation mix can be assumed based on scenarios from energy system models, by adjusting the share of each fuel in total energy consumption (in mtoe) both for households, and for the transport services sector.

Similarly, the macroeconomic and employment impacts of new technology deployment will depend on the relative comparative advantage and industrial leadership of each country/region.

4. Scenarios

The JRC-GEM-E3 model is used as a tool to compare counterfactual scenarios, representing for example the potential future evolution of technologies. Results are presented in terms of difference from a baseline scenario, which aims to capture a relatively stable evolution of global macroeconomic trends in the future, based on exogenous GDP projects.

4.1. Baseline

4.2. Scenarios and assumptions

The present modelling is based on the analysis of three scenarios, designed to capture alternative hypothetical evolutions of the road transport, and to isolate the impact of the technologies of interest. The main assumptions in technology deployment in the baseline and three scenarios are presented in Table 3.

¹⁰ EU Directive 2014/94 (European Parliament and Council of the European Union, 2014).

Table 3: Vehicle deployment assumptions for the 3 scenarios

2050 Values		Baseline	Electrification	Automation	Electrification & Automation	Sources
Market share of Electric Vehicles ¹ (% of new purchases)						European Commission (2018) Long Term Strategy EU from PRIMES ROW from JRC-POLES
Households	EU	57.42%	83.03%	57.42%	83.03%	
	ROW	46.26%	59.55%	46.26%	59.55%	
Transport Services	EU	[tbc]	[tbc]	[tbc]	[tbc]	
	ROW	[tbc]	[tbc]	[tbc]	[tbc]	
Share of Connected and Autonomous Vehicles % of total stock)						
Households	EU & ROW	0%	0%	[tbc]%	[tbc]%	tbc
Transport Services	EU & ROW	0%	0%	[tbc]%	[tbc]%	
Other Assumptions						
		Value		Source		
Reduction in maintenance costs		-25%		Letmathe,P., Soares, M., (2017)		
EV battery learning rates		16%		Tsiropoulos, et al. (2018)		
Labour productivity from automation		[tbc]				

¹ Consistent with other external inputs exogenously imposing fuel consumption (mtoe) by fuel (and therefore ensuring consistent in fuel mix and efficiency)

5. Results

6. Conclusions

References

- Aguiar, A., Narayanan, B., McDougall, R. 2016. " An Overview of the GTAP 9 Data Base" *Journal of Global Economic Analysis*, 1(1): 181-208. doi:10.21642/jgea.010103af
- Bloomberg New Energy Finance (BNEF). 2017a. "Why Battery Cost Could Put the Brakes on Electric Car Sales": <https://about.bnef.com/blog/why-battery-cost-could-put-the-brakes-on-electric-car-sales>
- Bloomberg New Energy Finance, (BNEF). 2017b. "When Will Electric Vehicles be Cheaper than Conventional Vehicles?" <http://www.automotivebusiness.com.br/abinteligencia/pdf/EV-Price-Parity-Report.pdf>
- Capros, P., Van Regemortel D., Paroussos, L., Karkatsoulis, P, Fragkiadakis, C., Tsani, S, Charalampidis, I, Revesz, T., Perry, M., Abrell, J., Ciscar Martinez, J.C., Pycroft, J., Saveyn, B., 2013. "GEM-E3 Model Documentation", *JRC Technical Report*, Publication Office of the European Union. doi:10.2788/47872
- Claybrook, J., and Kildare, S. 2018. "Autonomous vehicles: No driver...no regulation?" *Science*, 361 (6397): 36-37. doi: 10.1126/science.aau2715.
- CEDEFOP. 2014. Automotive sector and clean vehicles, Analytical Highlight, *EU Skills Panorama* http://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_Automotive_0.pdf
- European Commission. 2018. "On the road to automated mobility: An EU strategy for mobility of the future", *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. COM/2018/283. https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180283_en.pdf
- European Road Transport Research Advisory Council (ERTRAC). 2017. "Automated Driving Roadmap". ERTRAC Working Group on Connectivity and Automated Driving (version 8). <https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf>
- European Parliament and Council of the European Union, 22 October 2014, Directive 2014/94/EU on the deployment of alternative fuels infrastructure, *Off. J. Eur. Union* L 307:1-20.
- International Energy Agency (IEA). 2018. "Global EV Outlook 2018 - Towards cross-modal electrification." International Energy Agency. Paris, France. <https://webstore.iea.org/global-ev-outlook-2018>

- International Transport Forum (2017) Managing the Transition to Driverless Road Freight Transport, Policy Papers, No 32, OECD Publishing, [doi:10.1787/0f240722-en](https://doi.org/10.1787/0f240722-en)
- Keramidas, K., Tchung-Ming, S., Diaz-Vazquez, A. R., Weitzel, M., Vandyck, T., Després, J., Schmitz, A., Rey Los Santos, L., Wojtowicz, K., Schade, B., Saveyn, B., Soria-Ramirez, A. 2018. "Global Energy and Climate Outlook 2018: Sectoral mitigation options towards a low-emissions economy – Global context to the EU strategy for long-term greenhouse gas emissions reduction". JRC Science for Policy Report. Publications Office of the European Union. [doi:10.2760/674753](https://doi.org/10.2760/674753).
- Leech, J., Whelan, G., Bhajji, M., Hawes, M., and Scharring, K.. 2015. "Connected and Autonomous Vehicles - The UK Economic Opportunity" *KPMG and SMMT*.<https://home.kpmg.com/content/dam/kpmg/pdf/2015/04/connect-ed-and-autonomous-vehicles.pdf>
- Letmathe, P., Soares, M. 2017. "A consumer-oriented total cost of ownership model for different vehicle types in Germany", *Transportation Research Part D* 57: 314–335. [doi: 10.1016/j.trd.2017.09.007](https://doi.org/10.1016/j.trd.2017.09.007)
- Rueda-Cantuche, J.M. , Revesz, T., Amores, A., Mraz, M., Ferrari, E., Mainar, A., Montinari, L., Saveyn, B. , 2016. "The EU28 GTAP Input-Output Tables", Conference Paper, 19th Annual Conference on Global Economic Analysis, Washington DC, USA https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4936
- Schmidt, O., Hawkes, A., Gambhir, A., Staffell, I. 2017. "The future cost of electrical energy storage based on experience rates" *Nature Energy*, 6: 17110, [doi:10.1038/nenergy.2017.110](https://doi.org/10.1038/nenergy.2017.110)
- Skillful project, 2017. Skills and competences development of future transportation professionals at all levels - Future scenarios on skills and competences required by the Transport sector in the short, mid and long-term, Deliverable D1.1, <http://skillfulproject.eu/library?id=7603#>
- Thierer, A.D., and Hagemann, R.. 2015. 'Removing Roadblocks to Intelligent Vehicles and Driverless Cars', *Wake Forest Journal of Law & Policy*, 5 (2): 339-391, <https://www.mercatus.org/system/files/Thierer%26Hagemann-RoadblockstoDriverlessCars%28FINAL%29.pdf>
- Tsiropoulos, I., Tarvydas, D., Lebedeva, N.. 2018. "Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth", EUR 29440 EN, Publications Office of the European Union, Luxembourg, [doi:10.2760/87175](https://doi.org/10.2760/87175)
- Vandyck, T., Keramidas, K., Kitous, A., Spadaro, J., Van Dingenen, R., Holland, M., Saveyn, B, 2018. "Air Quality Co-Benefits For Human Health And Agriculture Counterbalance Costs To Meet Paris Agreement Pledges", *Nature Communications*, 9 (4939). DOI: [10.1038/s41467-018-06885-9](https://doi.org/10.1038/s41467-018-06885-9)

Wadud, Z. 2017. 'Fully Automated Vehicles: A Cost of Ownership Analysis to Inform Early Adoption', *Transportation Research Part A: Policy and Practice*. 101: 163-176. doi: [10.1016/j.tra.2017.05.005](https://doi.org/10.1016/j.tra.2017.05.005)

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